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Observation of Plastic and Elastic Deformations in Ge Films of Bonded GeOI

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Abstract

We directly observed mechanical strain and defect formation in GeOI with BOX by Raman and photoluminescence spectroscopies. Tensile strain near surface was almost elastic and it was released by exfoliating Ge film from BOX SiO_2. On the other hand, Ge close to BOX interface exhibits crystallinity degradation in addition to plastic strain. Thus, the BOX-interface-aware GeOI fabrication is definitely required for achieving high performance GeOI MOSFETs.

1. Introduction

Germanium on insulator (GeOI) structure is expected to be promising in place of conventional SOI in terms of further carrier mobility enhancement. Furthermore, ultra-thin Ge layer is required for aggressively miniaturized MOSFET application. However, it is reported that the mobility is severely degraded in thin GeOI[1]. It was indirectly claimed that the mobility was degraded due to the imperfect crystallinity at the back interface of Ge with buried oxide (BOX) [1]. This work reports Raman shift and photoluminescence (PL) results of both Ge films bonded on BOX-SiO_2 and those with BOX-free to directly characterize the back interface of Ge.

2. Experiment

GeOI (Ge 70 nm/ SiO_2 120 nm/ Si bulk) and bulk Ge for reference were used after cleaning by CH_3OH, HCl and HF. To exfoliate Ge film from BOX-SiO_2, GeOI wafers were patterned to be lines by photolithography and etched by diluted H_2O_2+NH_4OH solution, then BOX SiO_2 was removed immersing in HF (**Fig. 1 (2)**). After the exfoliation with a thermal-release tape (**Fig. 1 (3)**), both top-side (**Fig. 1 (5)**) and back-side (**Fig. 1 (6)**) of Ge in GeOI were measured by Raman and PL spectroscopy using Ar ion (488 nm) and second harmonic of Nd:YVO_4 (457 nm) laser, respectively.

3. Results and Discussion

Figure 2 shows typical Raman spectra in three samples (sample (A), (B), and (C)). The following two points should be noted. (i) A clear red shift from Ge wafer is observed on GeOI (sample (A)) on BOX-SiO_2 before the exfoliation. However, by exfoliating Ge film from BOX-SiO_2, the peak position shift from 299.2 in sample (A) changes to 299.9 cm^{-1} in sample (B), which means almost perfect recovery to the peak position (300.0 cm^{-1}) of reference bulk Ge (100) wafer. This fact shows for the first time that the Raman shift of the surface region is the elastic tensile strain. (ii) The back-side of Ge film (sample (C)) after detaching BOX-SiO_2 is still strongly distorted, as the peak position of the back-side is 297.4 cm^{-1}, which is quite lower than reference Ge wafer. These results indicate that not only the elastic deformation but also the plastic deformation occur at the back-side. Moreover, as we see in Fig. 2, the FWHM at the back-side is 5.3 cm^{-1}. It is very likely that polycrystalline, microcrystalline[2] and dislocation seem to be formed at the back-side. Namely, these defects are difficult to remove, once they are generated.

Figure 3 shows the typical PL spectra of three samples. It is noted that the peak assigned to direct band

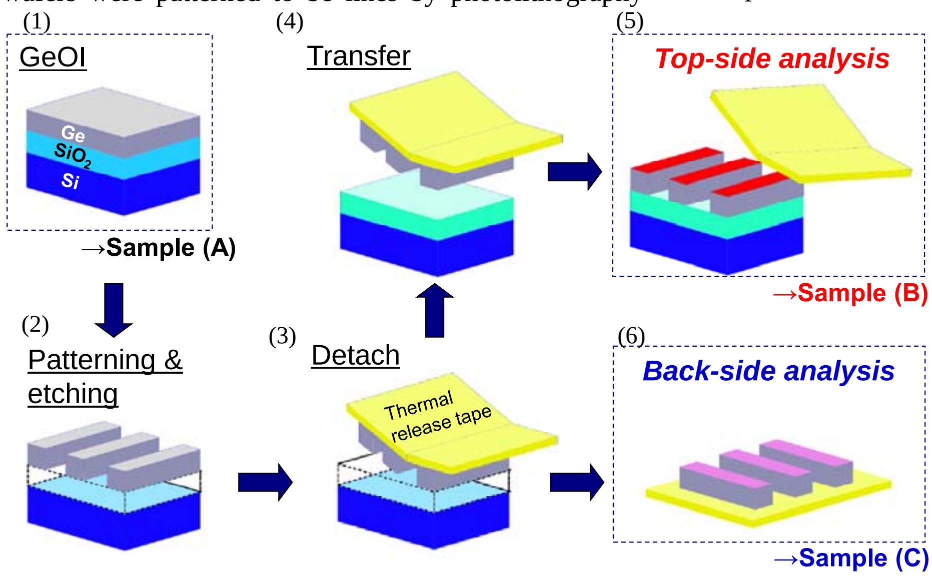

Fig. 1 Schematic images of sample fabrication to characterize. Ge film is first patterned by photolithography and H_2O_2+NH_4OH solution, and then BOX-SiO_2 is removed by HF. After exfoliating Ge from BOX-SiO_2, Ge film is detached by thermal release tape from the initial substrate, and back-side (BS) of Ge film on thermal release tape is analyzed. For the top-side (TS) analysis, Ge film was transferred to another fresh SiO_2/Si substrate.

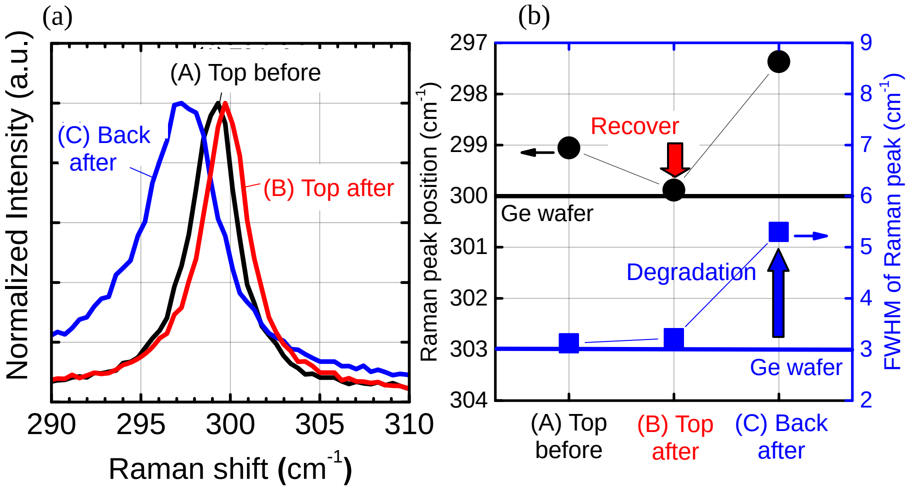

Fig. 2(a) Typical Raman spectra of three samples. "Top before", "Top after" and "Back after" means top-side before exfoliation, top-side after exfoliation and back-side after exfoliation, respectively. (b) Peak position and FWHM of observed Raman peak. Although the top surface of Ge film exhibits a red shift of Raman peak before detaching, the peak position recovers to the bulk Ge wafer position after detaching. It is due to a release of elastic strain caused by Ge/BOX interface. On the other hand, the red shift and peak broadening are observed on the back-side of Ge film even after detaching. It is inferred that Ge film close to BOX has a plastic deformation, and its crystallinity is severely degraded.

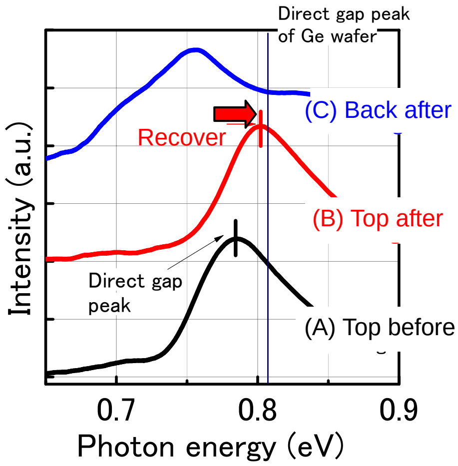

Fig. 3 Typical photoluminescence (PL) spectra of three samples. By exfoliating Ge from BOX, the PL peak assigned to direct gap of top-side Ge film increases up to the bulk Ge wafer position due to the release of bi-axial elastic tensile strain.

gap of GeOI bonded on BOX-SiO_2 (sample (A)) exhibits an energy shift to a lower from that of Ge wafer. The direct gap narrowing is reasonably explained by bi-axial tensile strain[3], and it is consistent with the red shift of Raman peak in sample (A). PL from the top-side of Ge film after exfoliating (sample (B)) shows the direct band gap increase due to the release of elastic strain. On the other hand, PL spectral from the back-side of sample (C)) after exfoliating Ge film is drastically changed. This fact directly indicates for the first time that the electronic structure is degraded by the plastic deformation and crystallinity degradation.

From these results, the deformation of GeOI is schematically summarized in **Fig. 4(a)**. The large degradation close to back-side interface has not been observed on SOI (data not shown). Therefore, we think Ge film degradation is due to the large mechanical stress which is induced by a large difference between thermal expansion coefficient of SiO_2 and Ge around room temperature, as shown in **Fig. 4(b).** Note a small thermal expansion coefficient difference between SiO_2 and Si. Thus, it is concluded that BOX material (or interface layer with Ge) for GeOI should be GeO_2 or Y_2O_3] whose thermal expansion coefficient is close to Ge. Furthermore, by engineering the BOX interface materials and processes, it might be possible to apply an intentional elastic strain on Ge film.

4. Conclusion

We have found two important aspects on bonded GeOI for the first time. (i) The tensile strain near the surface is caused by the elastic deformationC from the back-side and is almost released by detaching BOX-SiO_2. (ii) The stress in Ge near the interface with BOX-SiO_2 is quite strong and the Ge crystallinity is seriously degraded. Those results have been directly found for the first time by detaching BOX-SiO_2 from Ge film. Thus,

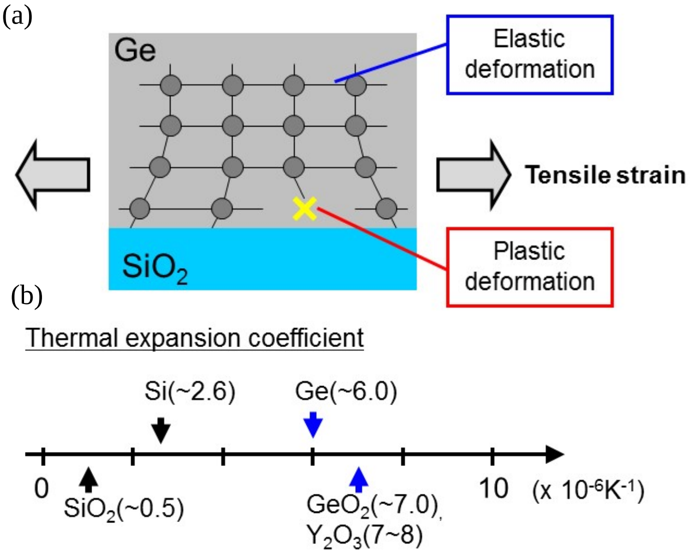

Fig. 4 (a) Schematic image of serious degradation of Ge film close to BOX-SiO_2. (b) Thermal expansion coefficient of Si, Ge, SiO_2, GeO_2[4] and Y_2O_3[5] around room temperature. Note that the difference between SiO_2 and Ge is much larger than that between SiO_2 and Si.

the BOX-interface-aware GeOI fabrication is definitely required for achieving high mobility in extremely thin GeOI MOSFETs.

Reference

*He is now with NTT Docomo Inc.

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